21 Landscape-Scale Model Relating the Nordic Mountain Birch Forest Spatio-Temporal Dynamics to Various Anthropogenic Influences, Herbivory and Climate Change

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A Spatio-Temporal Complexity in the Mountain Birch Forest Ecosystem: An Example

Consider two mountain birch forest patches of 10 ha each, where both patches have birch tree stems with an average age of 30 h years (i.e., “medium-aged”), but where the forest in the first patch consists of even-aged stems and the other patch includes a mixture of stems mostly of relatively very young and very old age, grouped into separate local subpathes (stands). Also assume that the landscape in question is susceptible for occasional tree-killing oubreaks of leaf-eating insects like *Epirrita autumnata*, and that old growth stands are managed (hypothetically) in accordance to industrial-like clear-cutting practices.

Even if both patches are characterized by mountain birch forest of similar average age for their respective stems at the scale of the 10 Ha patch, the former patch will probably avoid both disturbance from the *Epirrita* moth larvae and industrial-like logging events (clear-cuttings) over the nearest years, while the more heterogeneous patch may be radically more susceptible to disturbance from these factors due to the presence of subpatches containing older trees. The latter, smaller patches have reached the critical threshold for age-related disturbances, and are susceptible to perturbation either directly – as an initial spatial point of an attack – or indirectly as a consequence of attacks in the neighbourhood that is spreading to this site by domino effects (see main text).

Thus, a patch that in average terms can be described as “medium-aged birch forest site” at a given observational spatial scale [left square in Fig. 21A(a)] may over the following seasons either avoid attacks and grow into an old-aged site on average (marked as “A”), or it be set back to a young-tree site due to a direct or indirect attack (marked as “B”), depending on local details that are averaged out and thus invisible at this scale of observation [Fig. 21A(b)]; two leftmost squares]. A finer scale of observation would have revealed this difference in level of local heterogeneity, and thus susceptibility to disturbance [Fig. 21A(b), two squares split into four sub-squares each). In other words, threshold effects due to non-linear functional responses may lead to effects that can only be understood by studying the phenomenon over several spatial resolutions in parallel.

Further, if the disturbance susceptibility probability was a simple linear (i.e., proportional) function of age, and susceptibility was independent of events in the neighbourhood, the complexity from non-linear system response would not emerge [Fig. 21A(b); graph for stand maturation over time, marked as “A”]. In this case the overall state variable expressing the average age of stems in a given patch would not be inferior to a more fine-grained grid system of subcell-specific densities, except for the fact that more spatially finer-grained consideration of the subpatch heterogeneity would reduce the uncertainty with respect to forecasting attack within a given time interval: less “coarse-graining” reveals more local system detail, which again leads to a better forecast from the model. In this respect, larger uncertainty with respect to forecasting power is synonymous with a larger variance in attack rate as a function of patch state due to a systemtheoretically trivial coarse-graining effect [Fig. 21A(b); graphs marked as “B” and “C”].

However, if the disturbance susceptibility probability was *not* a simple linear (i.e., proportional) function of age *and* susceptibility was *dependent* on the neighbourhood through domino effects, complexity from non-linear system response may emerge. This property represents a challenge when it comes to understanding the system in modelling terms. For example, consider the situation in Fig. 21B. If perturbation events like insect attacks and logging are locally autocorrelated at the spatial scale of observation (i.e., neighbourhood influence), a neighbourhood like the left hand side of the central four-patch site will make the central site more susceptible to attack than a neighbourhood like the right hand side with fewer susceptible patches. Regardless of how many subpatches we had split the central patch into, we would still not be able to produce precise forecasts. The reason for this is that the uncertainty is a mixture of larger-scale neighbourhood influences as well as finer-scale details, not only the latter. In terms of strength of influence the domino effect dominates the spatio-temporal dynamics (triggering most local perturbations in the long run). A classical reductionistic approach by including more system details does not suffice in this case. We have to include a holistic, multi-scaled approach, involving methods beyond traditional tools and theory, in order to understand the dynamics. Only then can we expect to be in a position to produce as reliable statistical predictions as possible regarding the mountain birch forest’s spatio-temporal dynamics.

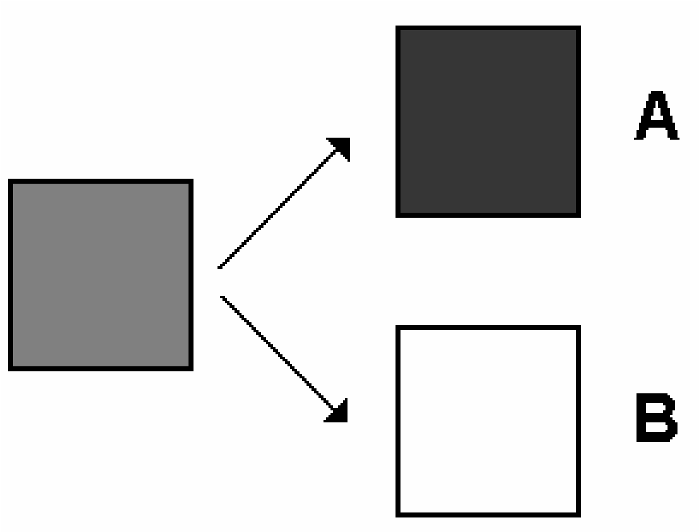

Fig. 21A(a). A local patch of mountain birch forest with medium-aged stems on average is illustrated as a *grey-shaded square* to the *left*. At finer resolutions this patch could be a mixture of young and old trees (i.e., a fine-grained mosaic of darker and lighter shades of grey would appear if we had included finer scale details inside the patch), or it could be even-aged and medium aged all over, showing the same shade of grey at all resolutions. Assuming a threshold effect for perturbations of birch forest stands the two situations can be expected to give different outcomes. For a heterogeneous stand the presence of old stems makes it susceptible for perturbations (see main text), which may remove old stems as well as some of the other stems due to neighbourhood effects. For a homogeneous stand, the probability of perturbation is small. Thus, without detailed knowledge of intra-patch age distribution of the stems we will not be able to produce a satisfactory forecast regarding future state of this patch. It could have been perturbed and set back to a patch of young stems (**B**), or it could have avoided a perturbation and grown into old-growth forest during this period (A)

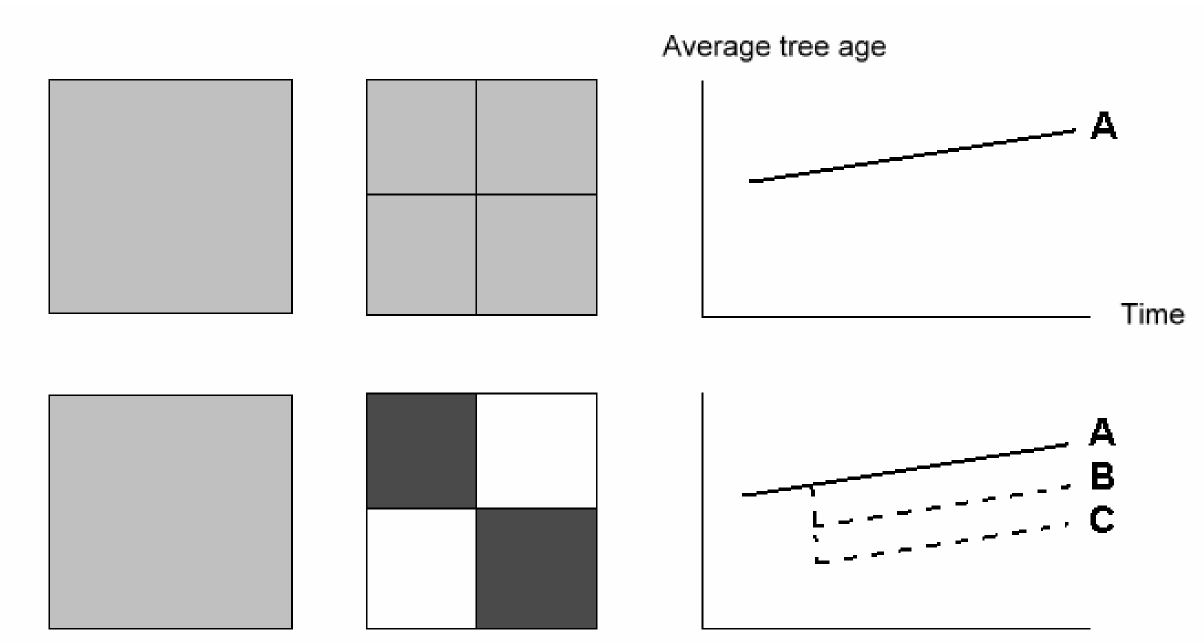

Fig. 21A(b). Two sites similar to the medium-aged site to the left in Fig. 21A(a) are shown as two *large grey squares* to the *left*, as examples of a finer-scaled homogeneity (*upper row*) and heterogeneity (*lower row*) situation, respectively. One of the sites is homogeneous with respect to average tree age also when we consider four subsites at finer spatial scale (*upper four-part square*), while the other site has a heterogeneous mix of young and old tree stands at this finer spatial scale (*lower four-part square*). In the *absence* of complex system dynamics in terms of domino effects between local neighbourhoods the two sites can be predicted to grow uninterruptedly and gradually into an old-aged site (“A” in *upper graph to the right*), or be perturbed by mild or more serious setbacks due to finer-scaled heterogenity of stand age (“B” and “C”, respectively, in the *lower graph*)

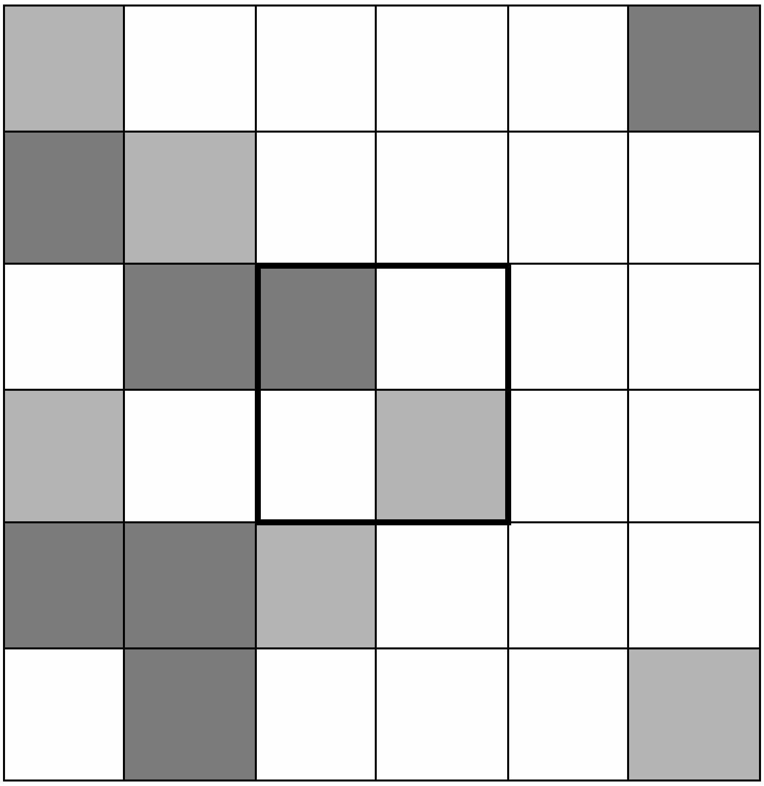

Fig. 21B. In Fig. 21A, we considered the consequence on predictive power of insufficient knowledge of details at *finer* resolutions (fine spatial scales). In this example we look at the effects from influence from the neighbourhood of the patch itself, i.e., from *coarser* spatial scales. A perturbation that starts in close or more distant vicinity to the central four-patch system in the illustration is more likely to spread to this patch through domino effects from one neighbourhood to the next if the perturbation originates in the *left-hand side* of the area, than in the *right-hand side*, due to fewer "stepping stones" of old- and medium growth forest to the *right*